Snow Remote Sensing with Ultra-Wideband Microwave Radiometry

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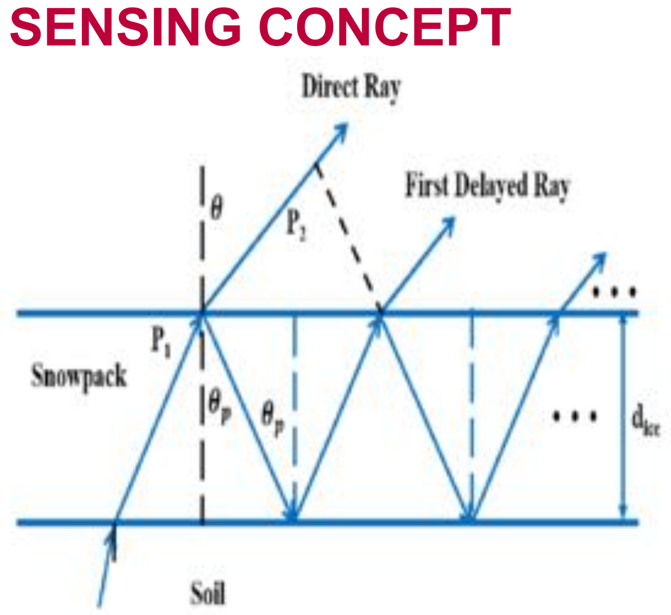
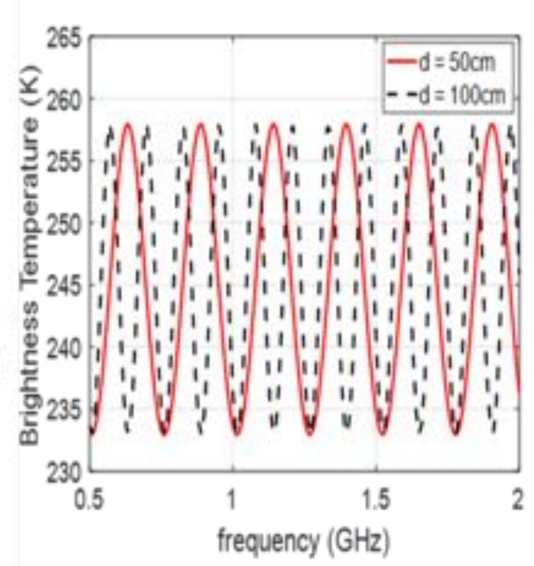
MOTIVATION

The recent development of ultra-wideband microwave radiometry at frequencies from ~ 500 MHz to ~ 2 GHz may offer new opportunities to address some of the challenges faced by current methods for remotely sensing snow pack thickness and water equivalent. The use of lower frequencies eliminates the influence of scattering from snow grains, and the use of multiple frequencies enables the search for oscillatory features in the brightness temperature versus frequency that strongly correlate to snow depth and snow water equivalent. This project is performing studies of the use of ultra-wideband microwave radiometry from 0.5-2 GHz for snow parameter sensing through both modeling and measurement activities; measurements involve both the UWBRAD and WiBAR sensors.

SENSING CONCEPT





Thermal emission from a two-layer medium can exhibit an oscillation versus frequency if "coherent" effects are present (i.e. multiple time delayed copies of an original noise signal are received due to layer reflections). The resulting oscillatory pattern in frequency provides information on layer electrical thickness as well as potential SWE information. The brightness temperature versus frequency can also be Fourier transformed to obtain the correlation function in time, in which time delay peaks indicate layer thickness.

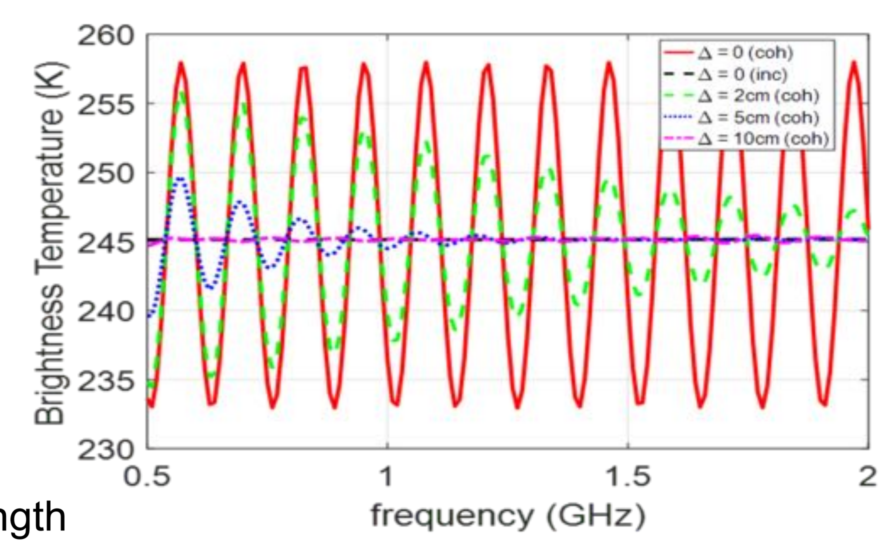
Observing oscillatory patterns requires significant reflections within the layer (i.e. at least moderate dielectric contrast), as well as "smooth" interfaces so that coherency is preserved. Lower frequencies are desirable to reduce surface roughness effects; low dielectric contrast however reduces the oscillatory amplitude. The available bandwidth also limits the precision with which snow thickness can be measured. Because only the oscillatory information may be needed, calibration requirements on radiometer measurements can be relaxed in part. However other TB variations with frequency may provide other information on medium properties.

Detailed studies of the expected thickness measurement precision are presented in Mousavi, DeRoo, et al, IEEE TGRS, pp. 1637-1651, Mar 2018

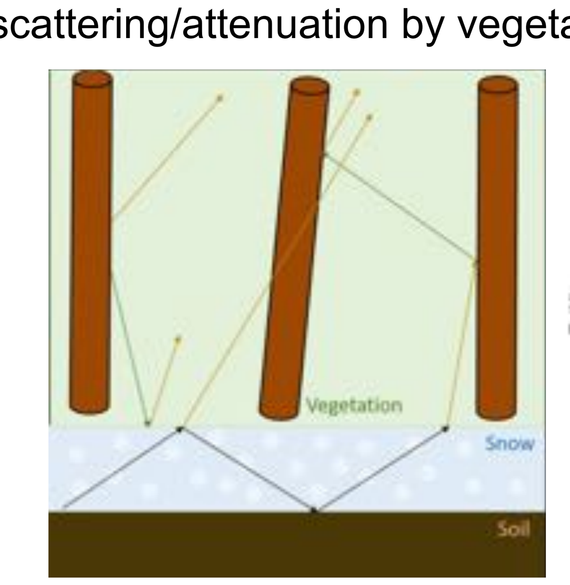
MODELING STUDIES

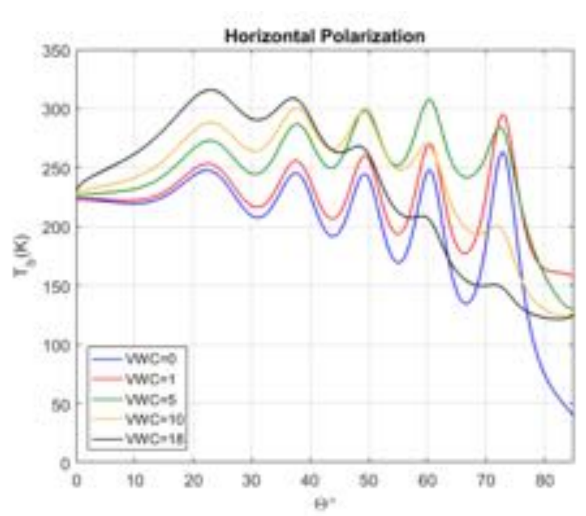
A key question for the project's modeling studies involves attempts to estimate the strength of coherent oscillations as a function of medium properties, surface roughness, and the presence of vegetation. An additional question involves the accuracy of thickness estimation for a non-uniformly sampled brightness temperature versus frequency in which particular frequency bands may be lost due to RFI.

Influence of roughness: A first estimate of roughness impacts can be obtained by averaging two-layer medium TB's over a distribution of layer thicknesses. The results show that roughness can significantly degrade oscillation amplitudes if it is significant vs. the observing wavelength

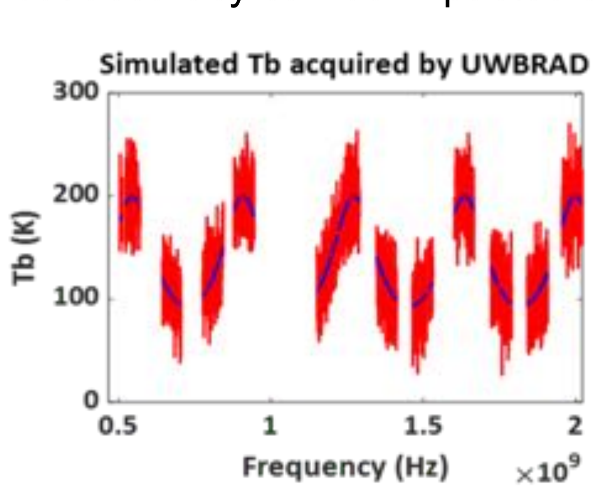


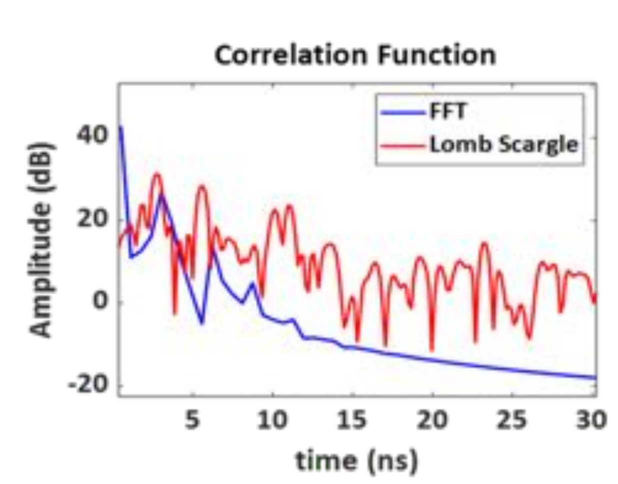
Impact of vegetation: Simulations versus angle also show that scattering/attenuation by vegetation can cause coherency loss





Impact of RFI: RFI is expected to cause significant corruption of radiometer measurements in the 0.5-2 GHz range. Real-time operating RFI detection and filtering algorithms can address this challenge in part, but frequently result in the loss of some portion of the spectrum. Reconstruction of the temporal correlation function can be performed using a Lomb-Scargle periodogram, but accuracy can be impacted as more data is lost.





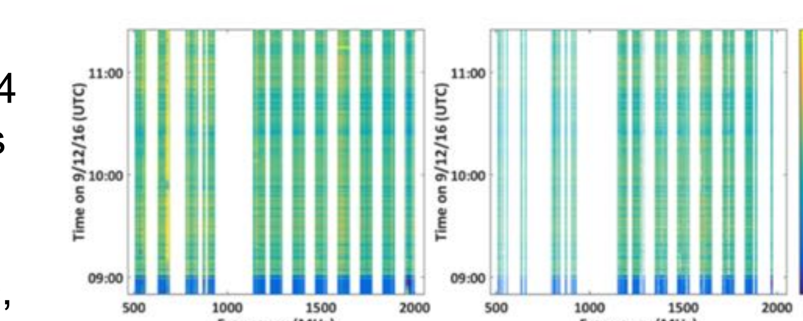
EXPERIMENTAL STUDIES

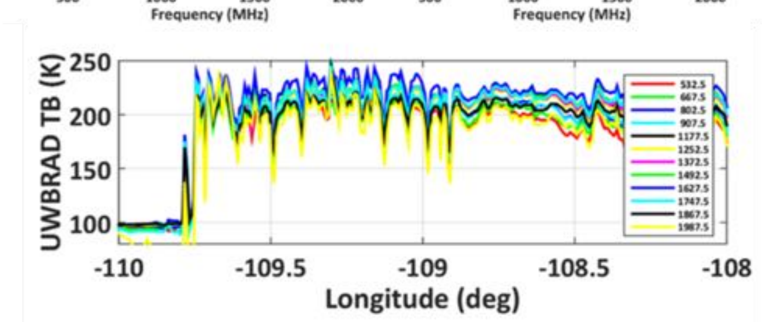
The project is conducting experiments using existing ultra-wideband radiometer systems available at OSU and UM. Both systems were developed under the support of the Instrument Incubator Program of NASA's Earth Science Technology Office.

UWBRAD: The Ultra-wideband Software-Defined Microwave Radiometer (UWBRAD) was developed at OSU and has been deployed in previous airborne campaigns in Greenland (Sept 2016 and Sept 2017) and Antarctica (Nov-Dec 2018) for observations of ice sheets and sea ice. Data over Northern Canada has also been acquired during transit flights.

Freq (GHz)	0.5-2 , 12 x ~ 88 MHz channels
Polarization	Single (Right-hand circular)
Observation angle	Nadir
Spatial Resolution	1.2 km x 1.2 km (1 km platform altitude)
Integration time	100 msec
Ant Gain (dB) /Beamwidth	11 dB 60°
Calibration (Internal)	Reference load and Noise diode sources
Calibration (External)	Sky and Ocean Measurements
Noise equiv dT	0.4 K in 100 msec (each 88 MHz channel)
Interference Management	Full sampling of 88 MHz bandwidth in 16 bits resolution each channel; real time "software defined" RFI detection and mitigation
Initial Data Rate	700 Megabytes per second (10% duty cycle)
Data Rate to Disk	<1 Megabyte per second

UWBRAD samples 0.5-2 GHz into 6144 frequency channels in 12 "sub-bands", and performs RFI filtering using pulse, cross-frequency, + kurtosis methods. Datasets from the transit flight show significant RFI but also the impact of inland water bodies.





WiBAR: The Wideband Autocorrelation Radiometer (WiBAR) was developed at UM and has been deployed in multiple snow field campaigns. WiBAR includes L- and S-band wideband radiometers to further extend the frequency bandwidth observed, and can be operated to measure at a variety of incidence angles.

Both UWBRAD and WiBAR are being used under the project to acquire new snow datasets.

NEXT STEPS

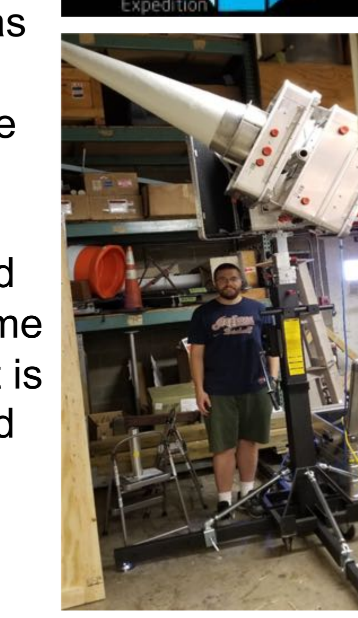
Project activities have included a deployment of WiBAR at the UM Biological Station in Pellston, MI during the Winter 2018-9 season, during which a time series of snow observations was acquired from a fixed vantage point. A wide variety of snow conditions occurred at this site over the season, so that information on varying geophysical scenes was obtained. These datasets are currently being analyzed for their implications for snow property sensing using ultra-wideband radiometry. It is noted that RFI was observed, and methods for addressing RFI impact on the datasets are under development.

The project is currently planning activities for the Winter 2019-20 season to include both WiBAR and UWBRAD observations. Potential options include a return to the UMBS station with both UWBRAD and WiBAR observing similar scenes, as well as ground-based tests at other locations as part of any joint SnowEx planned activities.

The project's modeling team is continuing the development of improved models for estimating the impact of roughness and vegetation on observed coherence. A particular current focus is the development of fully-numerical electromagnetic models for thermal emission from a two-layer medium having rough interfaces, in order to ensure that an accurate characterization of the degradations that may be caused by surface roughness is achieved.

Additional information on snow's impact on 0.5-2 GHz thermal emission will be obtained from a simplified UWBRAD system that is being deployed into Arctic sea ice as part of the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) sea ice campaign beginning September 20th. The instrument will be operated for approximately a 1 year period on an ice floe and acquire an extensive time series of brightness temperature data that is supported by numerous in-situ sea ice and snow property measurements being conducted by other investigators in the campaign.

MOSAiC International Arctic Drift Expedition



Finally the project team is interested in acquiring additional datasets through airborne deployment of UWBRAD as part of other SnowEx campaign activities. UWBRAD has previously operated from DC-3T and Twin Otter platforms, and requires only a modest aircraft installation footprint (an electronics rack and a "periscope" antenna deployment.) Any airborne deployment would provide the opportunity for extending existing knowledge of this technique for snow property sensing under a variety of environmental and snow conditions.

THE OHIO STATE UNIVERSITY

http://bprc.osu.edu/rsl/UWBRAD

ElectroScience LABORATORY